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Evolution of the role of the Consultant Engineer in High-speed Railway Projects along the last 25 years, in Spain

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Abstract

Over the last 25 years, the design of High-speed Lines in Spain has undergone an important evolution, which has been enhanced by the multitude of High-speed kilometers that have been built throughout the National territory, and by the multitude of problems and constraints, of very different nature, which have been identified as challenges and have resolved in a favorable way. IDOM having participate in 2,300 kilometers around the world as a specialized firm in the design and supervision of works for construction of High-speed lines, has lived first hand this evolution, contributing through its different projects and studies, to the development of the current Spanish High-speed model. In addition, it has subsequently been able to export the Spanish model, as a more appropriate solution, to other European Union countries, such as Poland and Sweden. Throughout this presentation, a brief review of the variation of design over the last 25 years will be made, quoting different projects that were engineering milestones, such as: the Basic Design and Works Supervision of the stretch Lalín - Santiago with 47 km in length; as well as the Detail Design and Works Supervision of the sub-section of Alcántara-Garrovillas Reservoir, which includes the Almonte viaduct, with a 384 m central arch, which is the world's longest span for a High-speed arch bridge. On the other hand, a short review will be done later on the major international projects of great relevance, which have currently been or will be designed, having the Spanish High-speed model as one of its main reference bases. The main objective of this presentation is to show the particular vision of the Consultant Engineer on the historical evolution experienced by the Spanish High-speed rail network, and to highlight the great strengths presented by the Spanish concept of design.

Keywords: Civil engineering evolution, Spanish High-speed rail, railway challenges

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1. Introduction

Over the last 25 years there has been an important evolution of the role developed by the engineering consulting firms that has been determined by the evolution of the administration, its regulatory framework and the increase of the quality requirements demanded in the development of High-speed Infrastructures.

Regarding to the evolution experienced by the engineering consultant, it is important to highlight the improvement of the production processes within the engineering field that have been strongly influenced by the appearance of the computation technology, by the appearance of protocols and methodologies related to the quality assurance and, with the improvements of the national regulatory framework as well as the modernization of the public administration. The role of the engineering consultant has evolved from an engineering based on the design of the product under a pattern of technical excellence towards a more global approach, of analysis of the complete life cycle of the infrastructure, taking into account from the design stage the phases of operation, maintenance and the phases of renewal of the infrastructure once it has reached the end of its life cycle.

In addition, the influence of the concern about the environmental sustainability has become very important, consolidating the procedure that guarantees the correct evaluation and mitigation of the affections that the works of High-speed are able to generate on the environment in which they are constructed.

Throughout this article, a historical summary of the kilometers of High-speed built throughout the national territory is going to be made, highlighting some projects that were a technological challenge. In parallel, it will be described the main evolutionary phases of the design process from the introduction of hardware as a tool to support design, to the development of BIM models. In addition, the main strengths of the Spanish High-speed model and its influence will be highlighted so that this model has been exported to other countries where relevant Highspeed projects are being developed today.

2. State of the art

2.1 Spanish High-speed network

The first High-speed line appears in Spain in 1992 to connect Madrid and Sevilla. This line was designed with ballasted track for a maximum speed of 300 km/h and also allowed the connection between Ciudad Real and Madrid, as shown by Gutierrez Puebla (2004). This line generated a significant increase in the mobility between the cities of Madrid and Ciudad Real, which come from 310,161 travelers in 1990 to 740,972 in 2000, having reduced travel time from 160 minutes to 50, as describes Ureña et al. (2005).

The Spanish High-speed model has been designed for the most part for a design speed of 350 km/h, however, currently the operating speed is limited to 300 km/h by the signaling system implemented. The network now has a total length of 2,938 km of High-speed lines built, and has a length of 904 km of tracks under construction and a length of 1,061 km of tracks in the planning or design phase, according to UIC (2017).

2.2 Technological evolution

During the construction of these 2,938 km, Spain experienced a great technological revolution regarding the design works for the High-speed network. Burdea Grigore and Coiffet (1994) showed the main advantages of the application of design software for the development of the project drawings, setting the bases of what was the computer graphic design. During this period, which began in the late 1980's, a complete migration from the traditional design model to virtual systems of representation was performed, increasing precision and efficiency in the project development.

Then, Anumba and Evbuomwan (1997) showed the beginnings of the development of collaborative models of work in the field of construction, with Internet as the main source of communication. In this way, work models and new management systems, as described by Boddy and Macbeth (2000), began to be implemented during this stage, in which it was not necessary for all the technical team of specialists to be in the same location. In the second place, these new collaborative models changed the communication channels that existed with the client, in this case the administration, turned it into an agent that could influence and verify the development of the different stages of the project being an active part in every moment during the design phase.

This stage will continue to evolve up to the present day, with the implementation of the latest collaborative work systems that in turn include a complete integration of design information into a virtual model, better known as BIM, acronyms of Building Information Modeling. Suermann (2009) shows the main advantages of the implementation of BIM in construction, highlighting the impact it will have on the projects that will be developed in the future. Subsequently, authors such as Chen and Luo (2014) or Matthews et al. (2015) show the advantages of applying these working procedures as tools for quality management. Finally, Cao et al. (2017) shows the implementation of these systems in China and the main influence they have got on the construction sector.

2.3 Design evolution

However, during this evolution period, not only the technical tools and work processes have been modified, but also the design concept itself has been modified to adapt to the modern quality standards that have the safety and the sustainability as two of its fundamental pillars.

The new approach to take into account the complete life cycle has been analyzed in detail by authors such as Hokstad et al. (1998) or Zoeteman and Esveld (1999). In addition, the administration has also been modernized following the appearance of the European Standard EN-50126, with its respective transpositions to the Spanish legislation through regulation 402/2013 and its amendment with Implementing Regulation (EU) 2015/1136, in order to ensure that a risk analysis based on the methodology included in the RAMS analysis is taken into account in the development of the projects, with the aim of guaranteeing lines with high levels of reliability, availability, maintainability and safety. This new design philosophy seeks to avoid the traditional model in which the most important was the correct definition of the product, to enter into a more global approach in which the complete life cycle of the infrastructure is analyzed.

Regarding the analysis of infrastructure sustainability, García Álvarez (2007) showed how some of the main High-speed lines in Spain generates a CO2 emission per traveler much smaller than the other modes of transport, including conventional rail, in the realization of those same journeys. In fact, he sets an example for the Madrid - Barcelona line with a CO2 emission per traveler which is a 20% of the CO2 emission that would be generated if the journey was made by plane. With this aim, a lot of innovative studies were carried out by developing new methodologies and models for energy footprint estimation, like the research provided by Chester et al. (2010).

3. Experimental analysis

3.1 Historical growth of the network

As shown below, Figure 1 describes the evolution of the Spanish High-speed network including the latest projects that are currently under construction, but are estimated to be completed before 2022, according to UIC (2017).

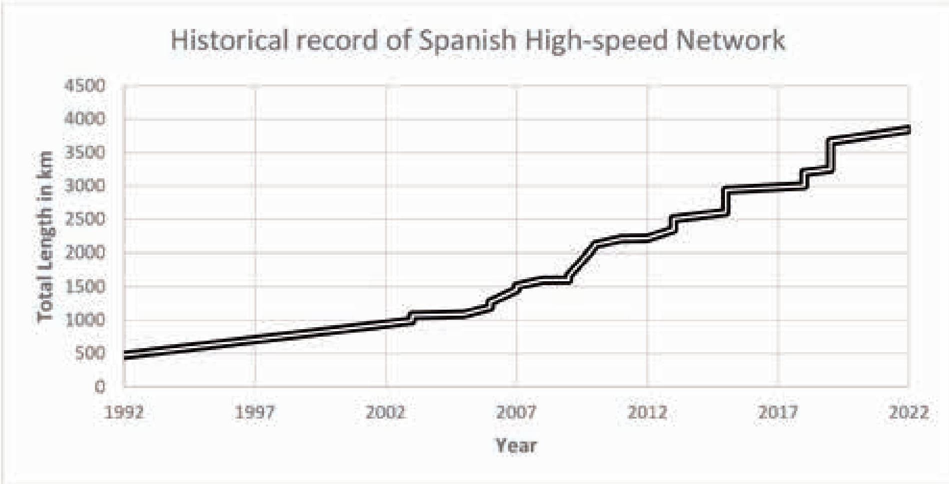

Figure 1. Total length of the Spanish High-speed network

As can be seen, the evolution of the Spanish High-speed rail network has experienced an linear growth since 2002, with an estimated growth between 2012 and 2022 of 1636 km, compared to the 1735 km already built between 2002 and 2012 and the 471 km built before 2002. This growth has been due to Europe's efforts to invest in the railways as a priority means to increase the connectivity of member states, especially the most peripheral, as is the case in Spain.

This strong investment derived from the political and social effort has progressed hand-inhand with the strong evolution experienced by the construction companies and especially by the consulting firms of design, which have improved the development and quality of its products to be able to face the technological challenge of developing the Spanish High-speed network, as shown above in the previous section.

3.2 Technological challenges of the Spanish engineering consultant

Some of these technological challenges have been due to the abrupt relief that exists throughout the Spanish geography and which, has forced, among other aspects, the construction of embankments with a height of more than 10 m. As shown by Melys (2006), this fact has generated that the solution of rail superstructure used in the network is that of ballasted track, since the slab track requires post-constructive settlements, that in countries like Japan or Germany, are limited around 30 mm, which forces, according to Esveld (2001), generally, to the construction of embankments that do not exceed 10 m in height. For this reason, the use of the slab track has been reduced only to specific cases, such as tunnels with a length of more than 1500 m, since their implantation in other sections would require a significant reduction of the height of the longitudinal profile of the infrastructure, generating a significant increase in the length of tunnels to be built throughout the High-speed network, with its consequent cost increase.

This hard relief has turned Spanish consultants into great specialists in the design of singular structures of great technical difficulty due to the number and length of tunnels and viaducts that have been necessary to be able to overcome the multitude of geographical features that exist in the environment of the Spanish High-speed network.

A clear example of this fact would be the project of the line Madrid - Galicia in its section between Lalín and Santiago. This project consisted of the development of 47 km of High-speed line for a design speed of 350 km/h, including the design of 15 viaducts and 18 tunnels, with an accumulative length of 9.74 km and 13.25 km respectively, representing a 49 % of the total length. Among the viaducts, it is worth to highlight the Viaduct over the Saramo River with 1,484 m in length and the Viaduct of O Eixo with 1,224 m in length, as shown in Figure 2.

Figure 2. O Eixo Viaduct in the High-speed line Madrid – Galicia

This technical excellence has been reflected later in other projects with unique structures such as the one developed in the High-speed line between Madrid, Extremadura and the Portuguese border, in the section between Alcántara and Garrovillas, where it was developed the design project of the Viaduct of Almonte to cross over the river Almonte in the vicinity of the Alcántara nature reserve. Figure 3 shows this viaduct, which constituted a world record of bridge arch typology, with a total length of 996 m, with the central arch having a span of 384 m.

Figure 3. Almonte Viaduct in the High-speed line Madrid – Extremadura – Portuguese Border.

(photo property of UTE AVE Alcántara-Garrovillas)

The stresses experienced by a High-speed bridge are much greater than those of a bridge of any other type due to the greater dynamic effects, the horizontal braking efforts, the effects of fatigue, etc.; On the other hand, there are strict additional functional considerations regarding deflections and accelerations, maximum length of expansion joints limited by technological reasons, etc. These considerations were included in the complete structural analysis of the viaduct, taking into account the viability of the construction, the integration in the reservoir environment, the correct structural response to the effects generated by the wind and, in conclusion, all the needed considerations to create a structurally efficient solution with simple and economical maintenance.

Regarding to signaling, it is necessary to emphasize that at present, in the Spanish railway network there are more than 1,800 kilometers that have installed the ERTMS system, of which almost 1,000 correspond with ERTMS level 2, which presents Spain as the country with greater implementation of this system, mainly associated with High-speed lines.

One of the main objectives of setting up a common European signaling system was to ensure technical interoperability and it is precisely this point which, with a great effort on the part of the suppliers and Adif, has been developed and validated in the Spanish High-speed network, guaranteeing high levels of punctuality and reliability, in all lines.

In order to guarantee interoperability not only with level 1 but also with level 2 of ERTMS, Spanish engineers are working, jointly, to achieve a correct communication between RBCs (Radio Block Center), which until now has been a great difficulty to achieve that interoperability in certain lines. Indeed, it is a proven fact, such as the work carried out in the Lleida-Barcelona section.

Also, the Albacete-Alicante High-speed line with 165 km long double track, operates exclusively with the last generation of ERTMS level 2 for the different types of trains operating in this line, also highlighting that it was possible to be implemented and put into service within a period of only 18 months.

3.3 Export of Spanish High-speed Model

In parallel to the achievement of these engineering milestones, there has been an export process in which Consulting companies have made important developments abroad thanks to this deep experience reached in the country of origin. These achievements include the example of the High-speed line Madrid - Lisbon, in which the Portuguese Administration planned an operation with mixed traffic, joining the High-speed traffic with the freight traffic.

This condition had a great importance during the design phase, having to develop a track with radii of curvature longer than 9000 m, or in other words, radii of curvature greater than those generally used in the Spanish lines of High-speed, with the aim of limiting the maximum cant to maintain the values of insufficiency and excess of generated cant, thus guaranteeing the possible coexistence between both traffics. In the phase of optimization of the alternatives of alignment, the most powerful tools that existed at the moment were used, such as Quantum software, which used genetic algorithms to obtain the three most favorable design alternatives for study in the preliminary design phase, along with the Environmental Impact Assessment.

On the other hand, it is also necessary to emphasize the design work provided for the development of the Polish High-speed network, in which more than 450 km of High-speed line were developed to connect the cities of Warsaw, Lodz, Poznan and Wroclaw, with a maximum design speed of 360 km/h. With respect to this project, it is important to highlight the work of revising the Spanish design standards to adapt them to the maximum speed of 360 km/h, taking into account the important design constraints derived from the low temperatures in Poland. These constraints forced to modify the existing solutions previously applied in Spain and to review, among other aspects, the design of the track bed layers, analyzing that the maximum stresses for each element were below the allowable limits and provided the necessary frost protection.

Currently, the Spanish engineering consultancy is also involved in the development of the first High-speed line in Sweden, in the East Link project, called Ostlanken in Swedish. This line has been designed to achieve operating speeds up to 320 km/h.

In addition, it should be noted that the Ostlanken project is being fully developed by implementing the BIM level 2 methodology in collaboration with Swedish designers, achieving a high degree of integration of all the technical specialties that are participating in the development of the project.

Within this international export of the Spanish Consultancy in the field of civil engineering, it is also worth mentioning the strong Spanish presence in the design of the Haramain High-speed Line in Saudi Arabia, the design of HS2 in the UK and participation in the High-speed line of California, in the United States. In this last project, the design of multicontinuous viaducts has been chosen, taking advantage of the best features of using the hyperstatic continuous viaducts, traditionally used in Spanish High-speed lines, which include the execution of a fixed point in one of the stirrups to avoid that there were important longitudinal stresses in the piles, what allows them to be slender, and secondly, also allows the reduction of the deck thickness.

On the other hand, multicontinuous viaducts avoid the main disadvantages associated with the design of long continuous viaducts, such as the need to execute expansion joints that present great movements and that constitute weak points of the line that demand a continuous and meticulous maintenance.

4. Conclusions

Throughout this article it has been developed a historical description of the main advances that the Consultancy has experienced in the field of civil engineering, during the last 25 years, since the implementation of the High-speed line between Madrid and Seville, going from the implementation of computer science to the introduction of modern working models such as the BIM methodology or the implementation of advanced calculation tools, such as those that incorporate the use of genetic algorithms to find the best solutions for the rail alignment.

These advances have been motivated by the important constraints existing in the Spanish territory, which have forced the consultant to achieve high levels of technical excellence, positioning Spanish engineering as a leader in the field of High-speed lines design, in the international scene.

This position has been evident with the development of international projects of great relevance that have been described throughout the previous points, highlighting in each of them the main improvements or advances provided by Spanish engineering.

Finally, the important work carried out in Spain regarding to the signaling systems has been mentioned, thus concluding the description of the main strengths that has been consolidated by Spanish engineering during the process of continuous evolution experienced in the last 25 years.

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